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6. AUTHOR(S)

Rebecca Woodgate and Knut Aagaard

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Polar Science Center, Applied Physics Laboratory
University of Washington
1013 NE 40th Street
Seattle, WA 98105-6698

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research, Team Leader Terri Paluszkiewicz
Ballston Centre Tower One
800 North Quincy Street,
Arlington, VA 22217-5660

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14. ABSTRACT

Our objective is to analyze data from the western Arctic Ocean and its adjacent seas in order to provide a measure of the variability of the shelf-basin system that is observationally based; identify, and where possible quantify, the important physical mechanisms controlling this system; contribute to the Shelf-Basin Interaction initiative (SBI), particularly in understanding the mechanisms of shelf-basin exchange; and promote further improvements in the rapidly growing array of models of arctic circulation and hydrographic structures and their variability, including providing patterns and statistics against which to test the fidelity of these models.

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An Extended Analysis of Time Series and Hydrographic Data with Reference to Shelf-Basin Interactions: Final Report

Rebecca Woodgate and Knut Aagaard
Applied Physics Laboratory, 1013 N.E. 40th, Seattle, WA 98105-6698
phone: 206-221-3268 fax: 206-616-3142 e-mail: woodgate@apl.washington.edu
phone: 206-543-8942 fax: 206-616-3142 e-mail: aagaard@apl.washington.edu

Award #: N00014-99-1-0321
http://psc.apl.washington.edu/HLD/

LONG-TERM GOALS

Our long-term research goals are to understand the circulation and physical properties of the high-latitude ocean, both mechanistically and quantitatively. We also seek to understand the links between physical processes, including those affecting the ice cover and the biology and chemistry of the high-latitude marine environment. The variability of the marine environment is a special focus and concern.

OBJECTIVES

Our objective is to analyze data from the western Arctic Ocean and its adjacent seas in order to provide a measure of the variability of the shelf-basin system that is observationally based; identify, and where possible quantify, the important physical mechanisms controlling this system; contribute to the Shelf-Basin Interaction initiative (SBI), particularly in understanding the mechanisms of shelf-basin exchange; and promote further improvements in the rapidly growing array of models of arctic circulation and hydrographic structures and their variability, including providing patterns and statistics against which to test the fidelity of these models.

APPROACH

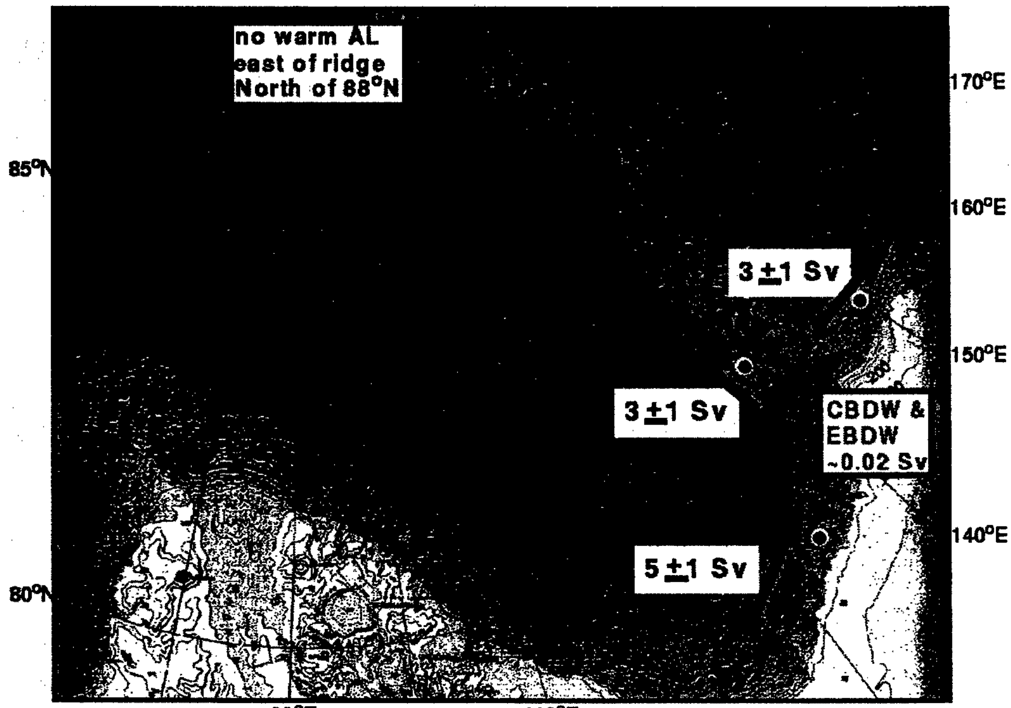
Our approach (collaborative with T. Weingartner, University of Alaska, Fairbanks) is the analysis and synthesis of historic sets of moored time series and hydrographic data from the western Arctic shelves, slopes and deeper basins. The synthesis addresses the circulation and water properties, with emphasis on the system dynamics, the climatology and statistics of the various fields, and the variability of the system, especially seasonal and interannual. In addition to refereed manuscripts and presentations at meetings, we submit these data to the established data centers via JOSS (Joint Office for Science Support, UCAR) and publish data and results via our web site.

WORK COMPLETED

This is the final report for this project. During this work, we have completed the quality control, synthesis, publication and archiving of significant data sets from the Lomonosov Ridge region of the Arctic Ocean and from the Chukchi Sea, providing data coverage for areas measured previously only sparsely, if at all. The work has resulted in four refereed journal articles accepted by or under submission to major journals (two articles still under submission at Deep Sea Research) and numerous lectures, conference papers, talks, and posters.

RESULTS

The first focus of our work is interaction between the shelf seas and the basins of the Arctic Ocean, including the links between the Arctic basins via the Arctic Ocean Boundary Current (AOBC). In Woodgate et al. (2001), measurements of water velocity, temperature and salinity from a set of three moorings deployed at the junction of the Lomonosov Ridge and the Eurasian continent allow quantification of the transport of the AOBC and, combined with CTD measurements taken in the Eurasian and Makarov basins, elucidate the role of Barents Sea waters in variability of the properties of the boundary current and the communication between the Eurasian and Canadian basins of the Arctic Ocean.



Map adapted from HDNO (1999)

Figure 1: Schematic summary of the transports and flow pathways of the Arctic Ocean Boundary Current near the junction of the Lomonosov Ridge with the Eurasian continent. Dots mark the three mooring positions. All three are in ca. 1700 m of water. One mooring is located on the continental slope of the Eurasian Basin ca. 6 degrees west of the junction of the Lomonosov Ridge with the continent. The second mooring is on the Eurasian flank of the Lomonosov Ridge at ca. 81N. The third mooring is on the continental slope of the Makarov Basin, ca. 6 degrees east of the junction of the Lomonosov Ridge with the continent. West of the ridge, the boundary current transport (cyclonic around the Eurasian Basin) is estimated at 5±1 Sv. This transport is split by the ridge into almost equal parts (3±1 Sv). Approximately 0.02 Sv of Eurasian Basin Deep Water (EBDW) and Canadian Basin Deep Water (CBDW) cross between the basins through a gap in the Lomonosov Ridge at ca. 80.4N. The topography of the HDNO chart (HDNO, 1999) indicates other deep (at least 1700 m) channels through the ridge north of this and south of 88N. North of 88N, the core of the Atlantic Layer (AL) is colder than south of this latitude, indicating the AL does not cross the Lomonosov Ridge north of 88N.

The boundary current flow, the main arterial transport system for the subsurface layers of the Arctic, is found to be dominantly barotropic, constrained to follow bathymetric contours and apparently independent of the local wind. Its transport of order 5 Sv is split by the Lomonosov Ridge, with approximately half the transport being diverted towards the North Pole by the Ridge and the other half continuing cyclonically along the Makarov Basin shelf. Small leakages of water both ways across the Lomonosov Ridge are found south of 88N on the Eurasian side (Figure 1). Although the mean flow is weak (5 cm/s or less), the current is rich in eddies (peak velocities 40 cm/s) which occur predominantly in two types - cold core eddies found in the upper 100-300 m probably of shelf origin, and warm-core eddies extending ca. 1000 m in the vertical probably formed from instabilities on an upstream front. Mooring and CTD data indicate a cooling and freshening of the Atlantic layer which is seem to propagate cyclonically with the AOBC around the Eurasian Basin, and CTD casts and ice-drift data, interpolated by the IABP program, are consistent with the change relating to interannual variability in the outflow from the Barents Sea, presenting a feedback mechanism for the ice-cover in the Arctic (Figure 2). Aagaard and Woodgate (2001) continue this theme addressing the distillation effect of ice formation and export on the internal structure and salinity budget of the Arctic Ocean.

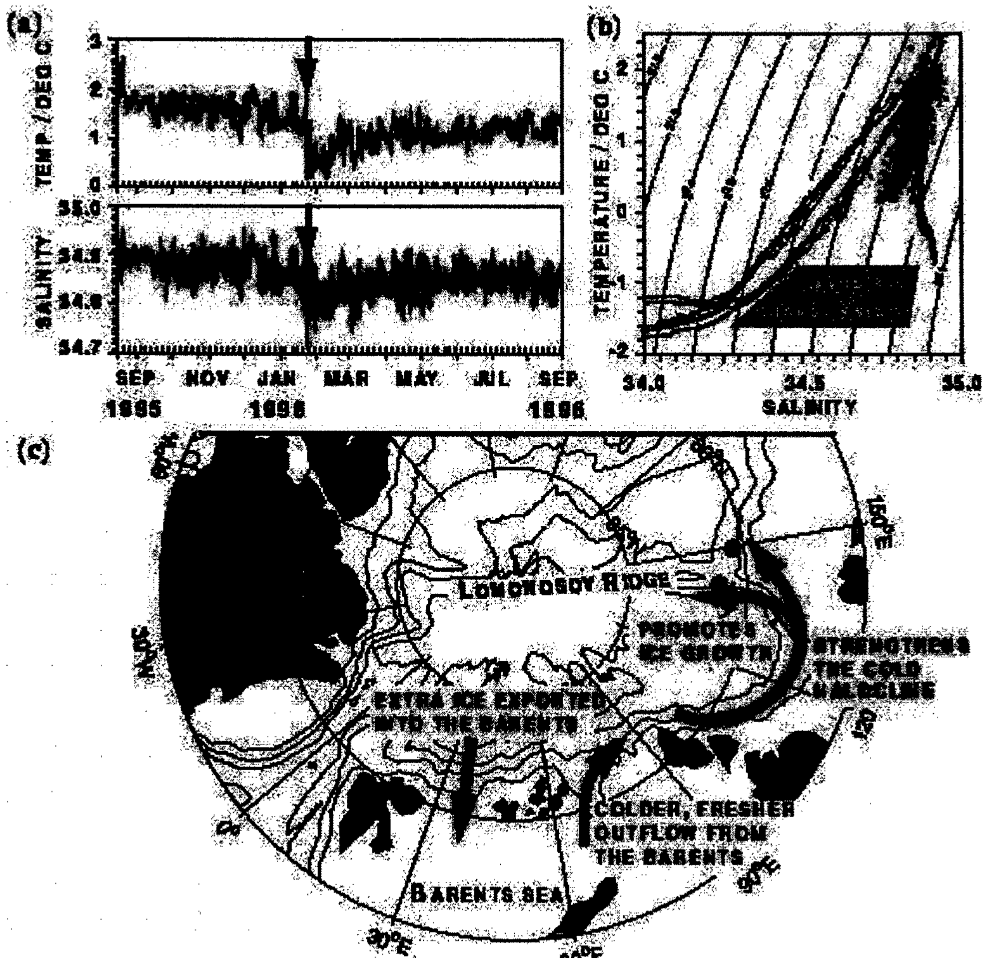


Figure 2: Time series (a) in the Atlantic layer at the westernmost mooring (x in (c)) show cooling and freshening in early 1996. On a T-S diagram (b), the spread of the data (mauve dots) shows isopycnal mixing of the warm, saline Atlantic core with Barents shelf waters (grey area). CTD profiles taken before (black lines) and after (blue lines) the cooling and freshening show that the shelf waters also strengthened the cold halocline layer (at salinities near 34.4 psu), reducing upward

heat loss and promoting ice growth. Similar changes (not shown) at the other two mooring sites (black dots) in July 1996 are consistent with the shelf signal advecting cyclonically along the continental slope and the Lomonosov Ridge with the mean flow observed at the moorings. We estimate that an additional 0.8 Sv of colder, fresher water exited the Barents Sea in winter 1994-1995, when twice as much ice entered the Barents Sea from the Arctic as in the preceding winter. This extra ice, together with atmospheric cooling, likely caused the freshening and cooling. This suggests a feedback mechanism, illustrated in (c), whereby extra ice exported from the Arctic Ocean into the Barents Sea can promote the growth of ice elsewhere in the Arctic. For further details, see Woodgate et al. (2001).

The second focus of our work is the role the Chukchi Sea in the local modifications of Pacific waters and their subsequent fate in the Arctic Ocean. The most comprehensive data set yet recorded, a set of twelve moorings deployed for one year throughout the Chukchi Sea (in both US and Russian waters, Figure 3), allows Woodgate et al. (submitted) to quantify the seasonal changes within the Chukchi and the local processes which influence the Pacific waters on their journey to the Arctic.

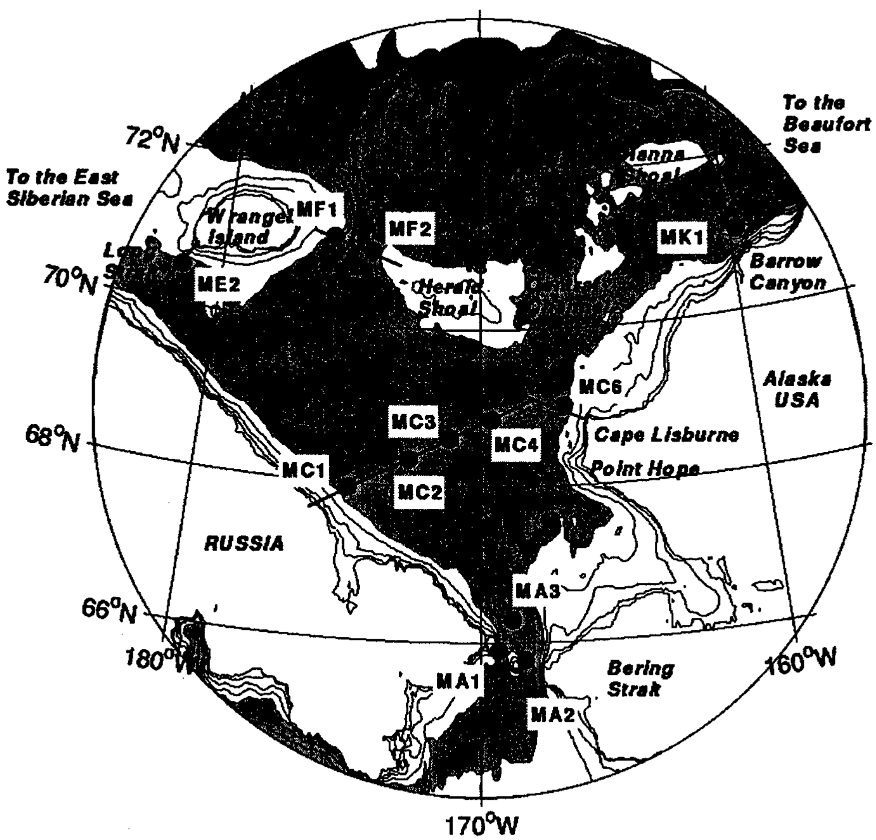


Figure 3: Schematic map of the Chukchi Sea, stretching from Bering Strait in the south (ca. 66N) to the shelf-break in the north (ca. 73N) and from Long Strait in the west to Barrow Canyon in the East. Dots show the twelve moorings used in Figure 4 below. See Figure 4 caption for description of mooring locations. Depth contours are every 10 m.

The flow field responds dominantly to the local wind, especially in the Bering Strait and eastern Chukchi Sea. High coherence over large space scales suggest the ocean is adopting the longer length scales of the atmospheric forcing. The mean flow is northward, presumably driven by a pressure head difference between the Pacific and the Arctic, which is opposed by the mean wind. Transit times for waters through the Chukchi vary considerably throughout the year and are in the range of 2-12 months. A strong seasonal cycle in temperature and salinity at depth, reaching the surface freezing point for most of the winter, indicates significant vertical mixing. Coastal currents in both the east and the west contribute fresher waters to the system whilst high saline waters from coastal polynyas form north of Cape Lisburne in the eastern Chukchi. Yet, a comparison of volumetric fluxes in temperature and salinity classes (Figure 4) suggests that the main role of the Chukchi is in the cooling of Pacific waters and, at least in a year without extreme coastal polynya activity such as 1990-1991, salinity modification within the Chukchi Sea is small, with the large seasonal cycles in salinity being predominantly advective from the south. Thus, the water properties entering through Bering Strait can be taken as a reasonable bellwether for those entering the Arctic Ocean, with corresponding implications for entry depth of the nutrient-rich Pacific waters into the Arctic Ocean water column.

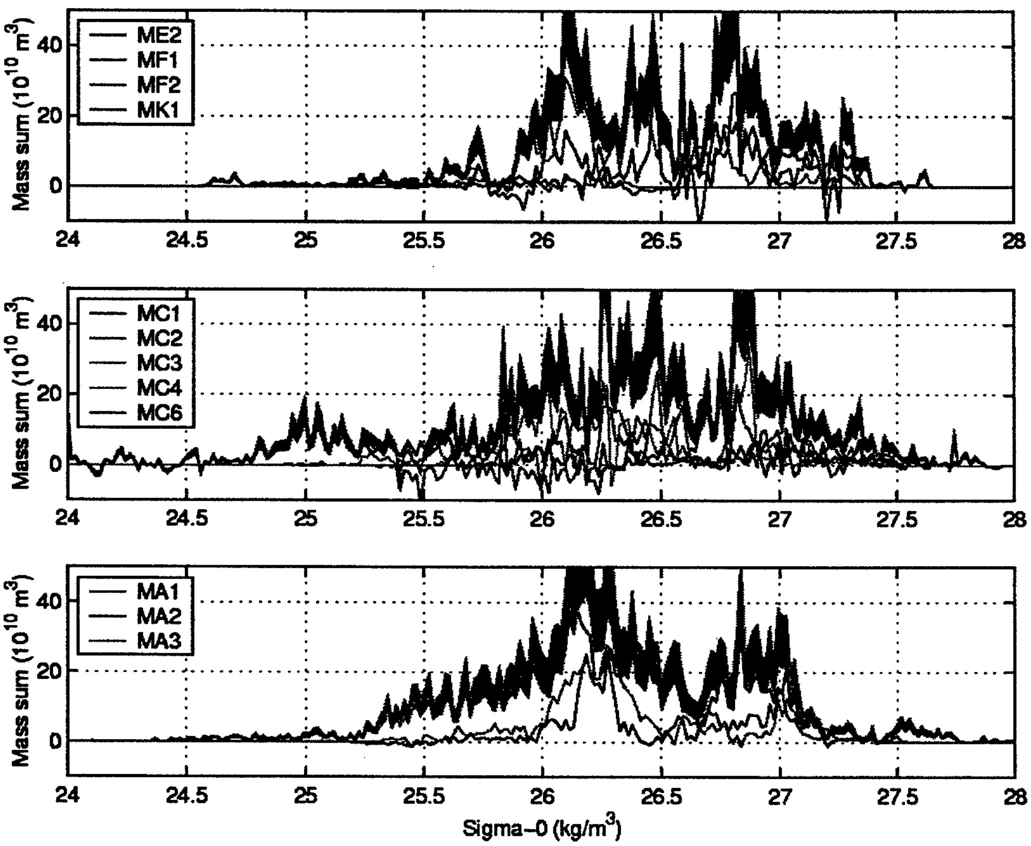


Figure 4:. Using temperature and velocity data from year-long mooring deployments in the Chukchi Sea and making suitable assumptions to convert velocity data to volume transports (see Woodgate et al., submitted), we calculate the annual mass flux in various salinity ranges through three zonal sections in the Chukchi. The three zonal sections are Bering Strait (bottom panel), the central Chukchi at ca. 68-69N (middle panel) and the combination of Long Strait, Herald Valley and Barrow Canyon outflow, see Figure 3. (Note the latter is representative of much of the flow through a zonal line at ca. 71N, which would also include the flow through the Central Channel.) Each panel (x-axis is salinity, y-axis is volume sum) indicates the total volume in each salinity class with errors (grey shaded region), with colored lines representing the contribution from individual moorings. (Bottom panel - MA1=western Bering Strait; MA2=eastern Bering Strait; MA3=proxy Bering Strait site, not included in the total sum (grey). Middle panel - moorings stretch from the Russian coast (MC1) to just off Cape Lisburne (MC6). Top panel - ME2=Long Strait; MF1=west

Herald Valley; MF2=east Herald Valley; MK1=head of Barrow Canyon. See also Figure 3). In all sections, the total transport is a multiple peaked function, with two main, broad maxima, one at ca. 32-33 psu and the other at ca.33.2 -33.8 psu. In all sections there is a strong minimum around 33.1 psu. For further details see Woodgate et al. (submitted).

As is most clearly illustrated by the pattern of ice-melt back, the flow through the Bering Strait appears to focus into four main outflows towards the Arctic (Figure 3), i.e. via Barrow Canyon, the Central Channel, Herald Valley and Long Strait. (Note that the southeastward-flowing Siberian Coastal Current is also intermittently present in Long Strait.). All outflows are comparable in magnitude and, with the exception of the Herald Valley outflow, appear to experience significant flow reversals, with, especially in Barrow Canyon, lower halocline and even upper Atlantic waters being found at anomalously shallow depths. The interannual variability of the flows of the northeastern Chukchi Shelf is discussed by Weingartner et al. (submitted).

IMPACT/APPLICATIONS

The impact of our work is a greater understanding of the physical processes important in the Arctic Ocean and neighboring Arctic seas, especially the circulation and dominant physical mechanisms both on the shelves (particularly the Chukchi Sea) and within the Arctic Ocean (particularly the Arctic Ocean Boundary Current). The results are relevant to the goals of SBI and to a greater understanding of the Arctic shelf-slope-basin system, including physical, biological and chemical cycling, with implications for local and global climate regimes. Quantitative data can be used to study interannual change, to understand on-going observations, and to quality control and improve the state-of-the-art generation of ocean models.

TRANSITIONS

The results of this project provide a background physical oceanographic framework for the ongoing SBI work, supporting both data analysis and field planning for the various physical, biological, and chemical programs of SBI. Various modeling PIs both within and external to SBI (e.g. Chapman, Winsor, Maslowski) are utilizing these datasets for model-data comparison. As the SBI fieldwork component completes this summer, the conclusions of these historic data will be valuable in data interpretation.

In addition, conclusions are directly beneficial to other studies by T. Weingartner (UAF) and ourselves, especially on-going observations and analysis of Bering Strait data (Aagaard and Woodgate, N00014-99-1-0345) and mooring and hydrographic data from the higher Arctic (Woodgate, Aagaard, Swift, Smethie and Falkner, NSF OPP-0117480). Inspiration from these data is leading to submitted (Nof and Woodgate, 2003) and future proposals for further observational efforts in the Arctic.

RELATED PROJECTS

This undertaking is fundamentally related to the multiple and interdisciplinary projects of the SBI program, both Phase I and Phase II (see e.g. http://sbi.utk.edu/). The synthesis and analysis is done in close collaboration with T. Weingartner (UAF) and other investigators, as evidenced by author lists on journal papers.

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